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## Bias voltage influence on the shape of cobalt-silicide nanowires

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### Abstract

We have fabricated cobalt-silicide nanowires on silicon by removing hydrogen from a passivated Si(001)2 × 1 surface with a scanning tunnelling microscope, followed by evaporation of cobalt. The apparent shape of the wires depends on the bias applied to the tip. This is due to the Fermi level pinning close to the valence edge by the high work function Pt–Ir tips, and the Co acceptor levels 0.35 eV above the valence band. Moreover, the decrement in the image contrast with increasing bias voltage is related to decrement in the local density of states, which is in qualitative agreement with former studies of nanosized cobalt disilicide islands.

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Over the past 10 years, there has been an explosive development of nanofabrication techniques in terms of scanning probe microscopy (SPM). This development will be essential for scientific progress in many areas of Physics, Materials Science, Chemistry, Biology, etc. [1–14]. These techniques will form enabling technologies for applications such as nanoelectronics, molecular electronics, micro-optical components, nanoelectromechanical systems, catalysis, etc. Advances are strongly supported by the highly engineered and successful lithography techniques that are used in microelectronics. One fundamental limit in lithography is imposed by the properties of the resist layer, since for the smallest feature size one would like the thinnest resist and/or the highest possible contrast. Although today conventional electron beam lithography is widely used to pattern features with dimensions larger than 10 nm [7], direct writing schemes based on SPM-lithography in combination with chemical vapour deposition (CVD) and physical vapour deposition (PVD) schemes of various metals and semiconductors (i.e. for Fe, Pd, Ni, Cd, Si, Al) [1–6,8–14] have led to feature sizes of less than 10 nm.

Nanoscale size metal patterns can be used as model systems to study the aspects of nanoscale electronics such as single electron tunneling (SET) [2]. An example design of a nanoscale device (SET transistor) is shown in Fig. 1, which was made by H desorption by the scanning tunneling microscope (STM) tip on a hydrogen (H)-passivated Si(100)2 × 1 surface. Indeed, since at room temperature (RT) the thermal energy is of the order of  $k_B T \approx 0.025$  eV, the island size has to be below 10 nm in order that the change in charging energy  $E_c = e^2/2C$  (with  $C$  the island capacitance) to satisfy the requirement  $E_c > k_B T$ , which is the necessary condition for SET [2].

Furthermore, metallization with Co merits special attention, since the latter is known to form Co-disilicide (CoSi<sub>2</sub>) with widespread applications in microelectronics (i.e. transistor gates, contacts, interconnects, etc.). This is due to the low electrical resistivity ( $\sim 14 \mu\Omega$  at RT) of CoSi<sub>2</sub>, and its small lattice mismatch that it has with Si (the lattice constant of CoSi<sub>2</sub> is  $\sim 1.3\%$  smaller than that of Si). Moreover, the strong similarity of the diamond structure of Si and the CaF<sub>2</sub> structure of CoSi<sub>2</sub> leads to a good epitaxial relationship at the CoSi<sub>2</sub>/Si interface. Finally, Co has also the advantage that all of its silicide phases are metallic [7].

Although the fabrication of Co-silicide (Co/Si) nanowires

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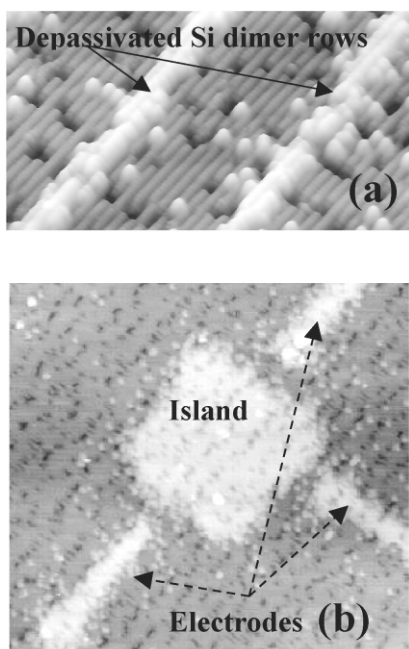


Fig. 1. (a) STM tip induced H-depassivation with current 3 nA, voltage 5.5 V, writing speed 100 nm/s. Filled state image with  $V_{sb} = 1.67$  V and  $I_t = 0.48$  nA. (b) Design of a single electron tunneling transistor with island size  $\sim 30 \times 30$  nm<sup>2</sup> onto a H-Si(100)2  $\times$  1 surface (Filled state image:  $V_{sb} < 0$ ).

was performed in earlier studies [6], so far there has not been any precise analysis of the effect of the bias voltage on the apparent shape and size of the STM imaged nanowires. The nanowire shape is expected in general to depend on the bias voltage, since it is a heterogeneous system of semiconducting and metallic in nature (with respect to electron tunneling) nanoscale surface structures. For metallic structures their simple electronic structure and the screening length of a few Angstroms makes the STM data interpretation straightforward. However, for semiconductors the situation can be more complex, since the Fermi energy lies near the conduction or valence band depending on doping (besides tip induced band bending, band bending due to charged impurities, etc.) leading to strong polarity dependence, since in STM conduction band charge can look different from valence edge charge.

The H-passivated samples were performed in ultra-high vacuum (UHV) where atomically clean Si(001)2  $\times$  1 surfaces were formed by resistive heating to remove the Si-oxide [6]. The Si wafer was lightly n-doped ( $\approx 10^{16} \times \text{cm}^{-3}$ ) with a miscut angle  $< 0.1^\circ$ . The reconstructed Si(100)2  $\times$  1 surface was dosed with atomic H from high purity molecular H<sub>2</sub>, which was dissociated by a hot ( $\sim 1500^\circ\text{C}$ ) W-filament at a distance of  $\sim 8$  cm from the Si substrate. The latter was kept at a temperature of  $\sim 400^\circ\text{C}$  to ensure monohydride coverage. The passivations lasted for 6 min at chamber pressure  $P_{\text{H}_2} \sim 3 \times 10^{-6}$  mbar. This

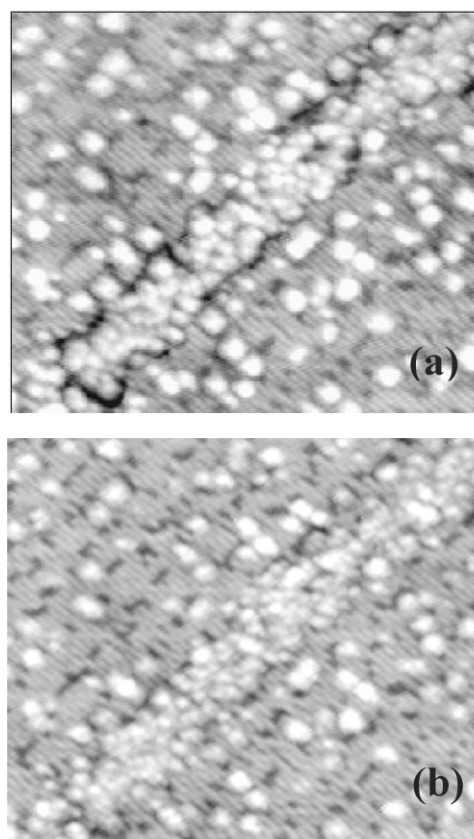


Fig. 2. Filled state images of Co-silicide wires with a scan size  $43 \times 43$  nm<sup>2</sup>,  $I_t = 33$  nA, and (a)  $V_{sb} = 1.52$  V, (b)  $V_{sb} = 1.93$  V (Filled state image:  $V_{sb} < 0$ ).

procedure resulted in a H dose of  $\sim 1080$  L (1 L =  $10^{-6}$  Torr s), which is sufficient to passivate fully the Si(100)2  $\times$  1 surface. Fig. 1 shows the STM tip induced depassivated sites. For the metallized wires in Fig. 2, 0.13 monolayers (ML) of Co were deposited onto the H-Si(100)2  $\times$  1 sample and subsequently annealed at  $410^\circ\text{C}$  for 20 s [6].

Fig. 2(a) shows that the Co/Si nanowire appears more granular and with larger feature sizes both laterally and out of plane, when imaged with lower bias voltage (in comparison with Fig. 2(b)). In addition, the height variations along the wires of Fig. 2 (which are shown in Fig. 3) show that the maximum out-of-plane variations decreased by  $\sim 0.2$  nm on increasing the sample bias voltage by 0.4 V. This potential change is comparable with the corresponding energy of 0.39 eV (above the valence band) of mid gap states in Si induced by Co impurities [8] (which are also highly reactive with Si [9]).

Indeed, during submonolayer deposition of Co on bare Si(001), interstitial Co diffusion and reaction with the Si substrate occurs [9]. STM studies have shown differences between filled and empty states of Co-silicide surfaces, which are due to variation in the local density of states

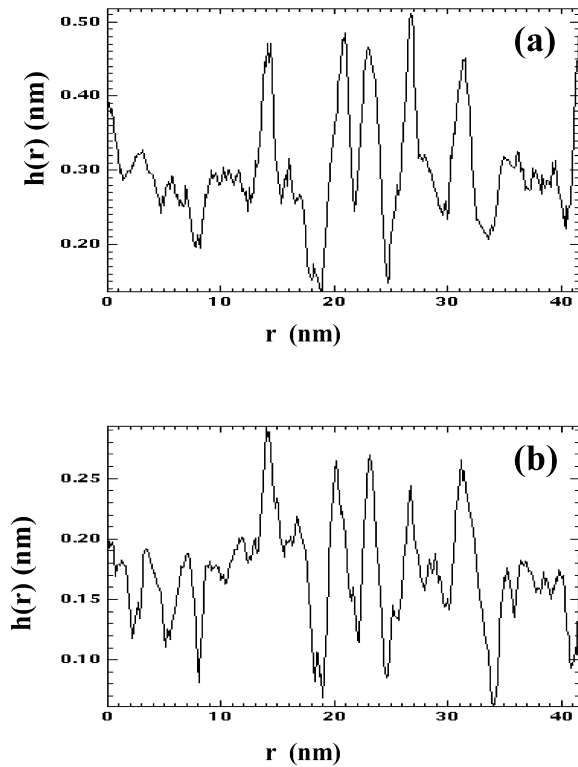


Fig. 3. Lines scans along the wires shown, respectively, in Fig. 2(a) and (b).

(LDOS), which is reflected by the observed contrast in the STM images [10]. The contrast change in Fig. 2 by changing applied voltage from  $\sim 1.5$  to  $\sim 1.9$  V shows indeed local changes in the density of surface states. This is not surprising, since the presence of Co impurities introduces energy levels within the Si band gap. There are two acceptor levels at 0.35 and 0.49 eV above the valence band, and a donor level at 0.53 eV below the conduction band [11].

STM tip induced gap states are excluded in the present study, since they occur under small sample bias voltages ( $< 1$  V) [12], while at higher bias voltages the current between tip and sample is dominated by the tunneling process between the tip and the conduction band and therefore the current depends exponentially on the tip-sample distance [13]. The use of Pt–Ir tips which is a high work function material ( $\approx 5.5$  eV) can lead also to pinning of the Fermi level close to the edge of the valence band, and it prohibits any spectral shifts arising from tip induced band bending due to formation of an inversion layer in n-type Si [14]. With Pt–Ir tips, Si band gaps of approximately 1.1 eV were determined for both n and p-type Si [14]. In addition, STM spectroscopy measurements ( $I_t - V_{sb}$  curves) on CoSi<sub>2</sub> islands showed that the Fermi energy  $E_F$  was located at  $0.35 \pm 0.05$  eV above the valence band which is in agreement of possible Fermi level pinning by the energy-

tically lowest acceptor states of Co within the Si band gap [10].

For CoSi<sub>2</sub> islands prepared by 1.5 ML of Co deposition onto Si(100) $2 \times 1$  (held at 500 °C) revealed voltage dependence which was the reverse than those expected from the LDOS of bulk Co and Si [15]. In the same work, it was shown that for sample bias voltages below (including also the negative bias voltages) 0.3 V, the observed protrusion on the CoSi<sub>2</sub> islands were Si atoms [15]. In our case (Fig. 2) where 0.13 ML of Co were deposited onto Si sample and annealed at 410 °C for 20 s, we expect the formation of a cubic CoSi and/or CoSi<sub>2</sub> phases. Indeed, we cannot distinguish between these two phases since the atomic protrusions for Si are identical which also constitute the imaging species in our case based on the previous discussion [15]. For filled state imaging, only electrons with energy states in the range from  $E_F - e|V_{sb}|$  to  $E_F$  contribute to the tunneling current through the integrated local density of states (ILDOS). Previous calculations of the ILDOS for CoSi<sub>2</sub><sup>1</sup> indicated a decrease in ILDOS for bias voltages  $V_{sb} < -1.3$  V, which is consistent with the decrement in surface corrugation shown in the STM images for more negative bias voltages.

In conclusion, we have shown that the shape of Co-silicide nanowires onto Si(001) $2 \times 1$  reconstructed surfaces depends on the sample bias voltage  $V_{sb}$  during STM (filled state) imaging. This effect is due to the Fermi level pinning close to the valence edge by the high work function STM Pt–Ir tips, and the Co acceptor levels at 0.35 eV above the valence band. The observed decrement in the image contrast with increasing bias voltage  $V_{sb}$  is related to decrement in the LDOS, which is in qualitative agreement with former STM spectroscopy studies of nanosize CoSi<sub>2</sub> islands [15].<sup>1</sup>

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### References

- [1] T.-C. Shen, C. Wang, G.C. Abeln, J.R. Tucker, J.W. Lyding, Ph. Avouris, R.E. Walkup, *Science* 268 (1995) 1590.
- [2] J.W. Lyding, T.-C. Shen, J.S. Hubacek, J.R. Tucker, G.C. Abeln, *Appl. Phys. Lett.* 64 (1994) 2010. E.S. Snow, P.M. Campbell, F.K. Perkins, *Naval Res. Rev.* XLIX (1997) 15. J.W. Lyding, *Naval Res. Rev.* XLIX (1997) 25. E.T. Foley, A.F. Kam, J.W. Lyding, Ph. Avouris, *Phys. Rev. Lett.* 80 (1998) 1336.

<sup>1</sup> See in Ref. [15] the top panel of Fig. 3 which shows the variation of ILDOS for CoSi<sub>2</sub>.

- [3] T.-C. Shen, C. Wang, J.R. Tucker, Phys. Rev. Lett. 78 (1997) 1271.
- [4] K. Tsubouchi, K. Masu, Thin Solid Films 228 (1993) 312. K. Tsubouchi, K. Masu, K. Sasaki, Jpn. J. Appl. Phys., Part 1 32 (1993) 278.
- [5] (a) D.P. Adams, T.M. Mayer, B. Swartzentruber, Appl. Phys. Lett. 68 (1996) 2210. T.M. Adams, B. Mayer, Swartzentruber, J. Vac. Sci. Technol., B 14 (1996) 1642. See also D.P. Adams, L.L. Tedder, T.M. Mayer, B.S. Swartzentruber, E. Chason, Phys. Rev. Lett. 74 (1995) 5088. R.R. Kunz, T.M. Mayer, J. Vac. Sci. Technol., B 6 (1988) 1557.
- [6] G. Palasantzas, B. Ilge, L.J. Geerligs, J. den Nijs, J. Appl. Phys. 85 (1999) 1907. G. Palasantzas, B. Ilge, L.J. Geerligs, J. den Nijs, Microelectron. Engng 46 (1999) 133. B. Ilge, G. Palasantzas, L.J. Geerligs, Appl. Surf. Sci. 144–145 (1999) 543. G. Palasantzas, B. Ilge, L.J. Geerligs, J.M.M. de Nijs, Surf. Sci. 412–413 (1998) 509.
- [7] L.F. Matheiss, D.R. Hamann, Phys. Rev. B 37 (1988) 10623. H. von Känel, C. Schwarz, S. Gncalves-Conto, E. Müller, Phys. Rev. Lett. 74 (1994) 1163.
- [8] T. Komeda, Y. Morita, H. Tokumto, Surf. Sci. 384 (1996) 193.
- [9] V. Scheuch, B. Voigtlander, H.P. Bonzel, Surf. Sci. 372 (1996) 71. R.E. Weber, Appl. Phys. A 30 (1988) 1. H. Meyerheim, U. Dobler, A. Puschmann, Phys. Rev. B 44 (1991) 2211. M. Copel, R.M. Tromp, Appl. Phys. Lett. 65 (1994) 312. P.A. Benett, D.G. Cahill, M. Copel, Phys. Rev. Lett. 73 (1994) 452. R.T. Tung, J.M. Gibson, J.M. Poate, Appl. Phys. Lett. 42 (1983) 888.
- [10] B. Ilge, Scanning Tunneling Microscopy of Cobalt on Silicon Surfaces, PhD Thesis, Delft University of Technology, 2000. B. Ilge, G. Palasantzas, L.J. Geerligs, J.M.M. de Nijs, Surf. Sci. 414 (1998) 279.
- [11] S.M. Sze, Physics of Semiconductor Devices, Wiley, New York, 1981.
- [12] H.-A. Lin, R.J. Jaccodine, M.S. Freud, Appl. Phys. Lett. 74 (1998) 1105. E.T. Yu, Mater. Sci. Engng R 17 (1996) 147. H.-A. Lin, R.J. Jaccodine, M.S. Freud, Appl. Phys. Lett. 72 (1998) 1993.
- [13] L.D. Lang, Phys. Rev. B 37 (1988) 10395.
- [14] H.-A. Lin, R.J. Jaccodine, M.S. Freud, Appl. Phys. Lett. 74 (1998) 2462. T. Yu, K. Barmak, P. Ronseheim, M.B. Johnson, P. McFarland, J.-M. Halbout, J. Appl. Phys. 79 (1996) 2115.
- [15] B. Voigtlander, V. Scheuch, H.P. Bonzel, S. Heinze, S. Blügel, Phys. Rev. B 55 (1997) 13444.